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FINAL REPORT - PHASE 1

W71-ΦΦ623

FEASIBILITY OF A PERIODIC FLUSHING SYSTEM FOR COMBINED SEWER CLEANSING

R-2608

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27 Abstract

One of the causes of pollution from stormwater overflow of combined sewers is the deposition of pollutional solids during dry weather flow followed by pick up of the pollutional material during storm flow when the flow be bypassed. As a solution to this problem, it has been proposed that a flushing system be used to periodically cleanse the sewers during dry weather and convey the solids to the treatment plant. ~~Under Phase I~~ A study was made of sewer flushing practices, application requirements, and hydraulic theory. Investigation was also made of sampling methods and equipment; flushing test equipment was designed ~~for use in Phase II~~, and the cost ~~of Phase II~~ was estimated. It was confirmed that additional detailed information is needed to apply a periodic flushing system to actual combined sewers. It was also concluded that the existing information on sewer flushing indicated a good possibility that a periodic flushing system would be feasible for reducing pollution from combined sewer stormwater overflow. ~~The detailed information needed to~~ apply a sewer flushing system must be determined by a large number of controlled experiments of flushing effectiveness. The design of flushing evaluation equipment ~~for use in Phase II~~ has been carried to the point that cost estimates can be made for construction of the equipment. A description of the design and the cost estimates are included ~~in this repo~~ (WRSIC abstract)

Abstractor | Institution

CE 45363
August, 1967

FINAL REPORT - PHASE I

FEASIBILITY OF A PERIODIC FLUSHING SYSTEM FOR COMBINED SEWER CLEANSING

R-2608

The research upon which this report is based was performed pursuant to Contract No. 14-12-19 with the

Federal Water Pollution Control Administration
United States Department of Interior

Prepared By

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ABSTRACT

Published literature has shown that one of the causes of pollution from stormwater overflow of combined sewers is the deposition of pollutional solids during dry weather flow followed by pick up of the pollutional material during storm flow when the flow must be bypassed. As a solution to this problem it has been proposed that a flushing system be used to periodically cleanse the sewers during dry weather and convey the solids to the treatment plant.

This is a final report of the work done by FMC Corporation, Central Engineering Laboratories under a six month contract, Contract 14-12-19, from the Federal Water Pollution Control Administration to study the Feasibility of a Periodic Flushing System for Combined Sewer Cleansing.

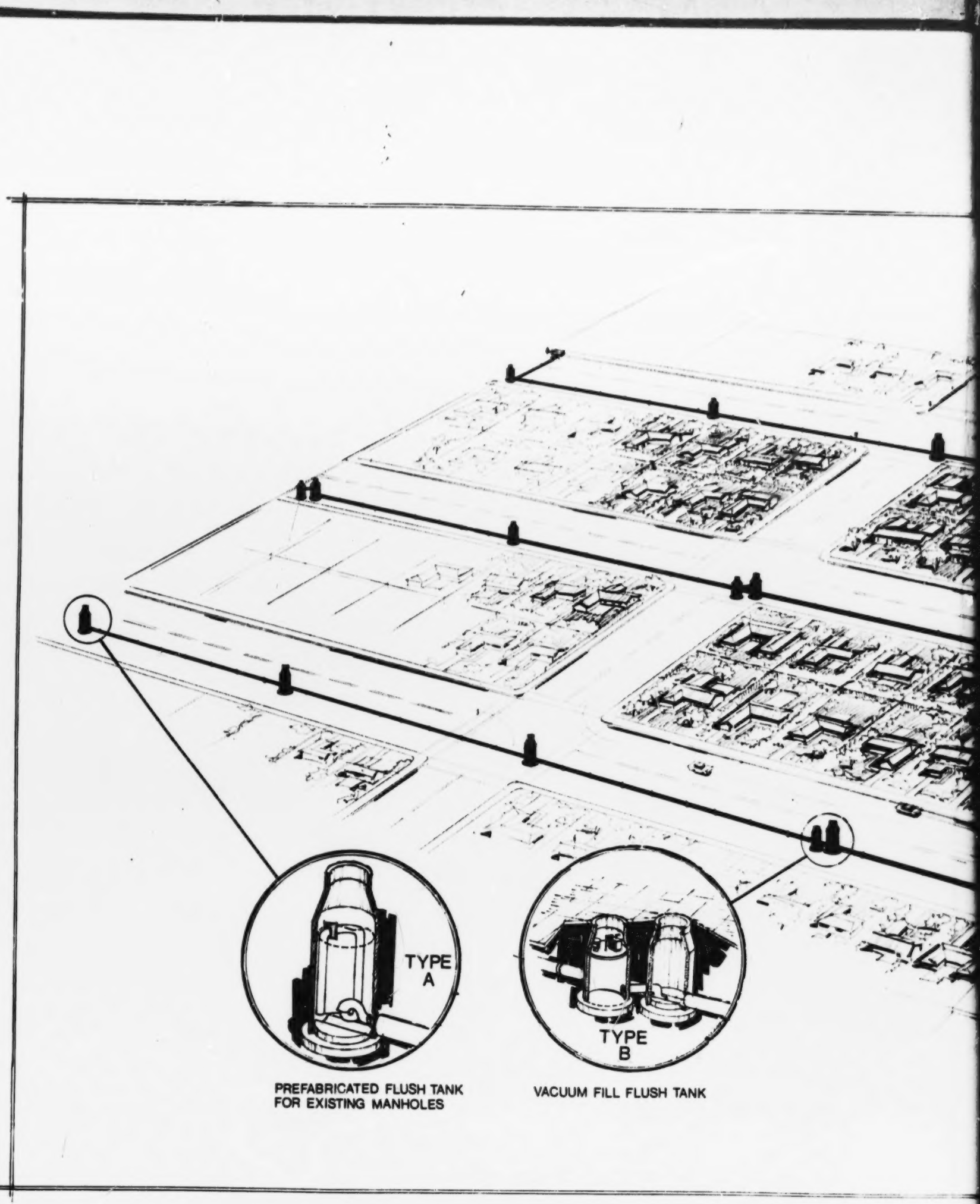
Under this Phase I contract a study was made of sewer flushing practices, application requirements and hydraulic theory, an investigation was made of sampling methods and equipment, and flushing test equipment was designed for use in Phase II and the cost of Phase II was estimated.

In the course of the various background studies it was confirmed that additional detailed information is needed in order to apply a periodic flushing system to actual combined sewers. It was also concluded that the existing information on sewer flushing indicated a good possibility that a periodic flushing system would be feasible for reducing pollution from combined sewer stormwater overflow.

The detailed information needed to apply a sewer flushing system must be determined by a large number of controlled experiments of flushing effectiveness.

The design of flushing evaluation equipment for use in Phase II has been carried to the point that cost estimates can be made for construction of the equipment. A description of the design and the cost estimates are included in this report.

It is recommended that this program be continued into Phase II in order to determine the effectiveness of flushing under various conditions. The work in Phase II should also include the integration of the test results into a design procedure, the design and development of flush station equipment and control systems, the selection and approval of a demonstration location for Phase II, and the preliminary design and cost estimation for the Phase III demonstration.



PREFABRICATED FLUSH TANK
FOR EXISTING MANHOLES

VACUUM FILL FLUSH TANK

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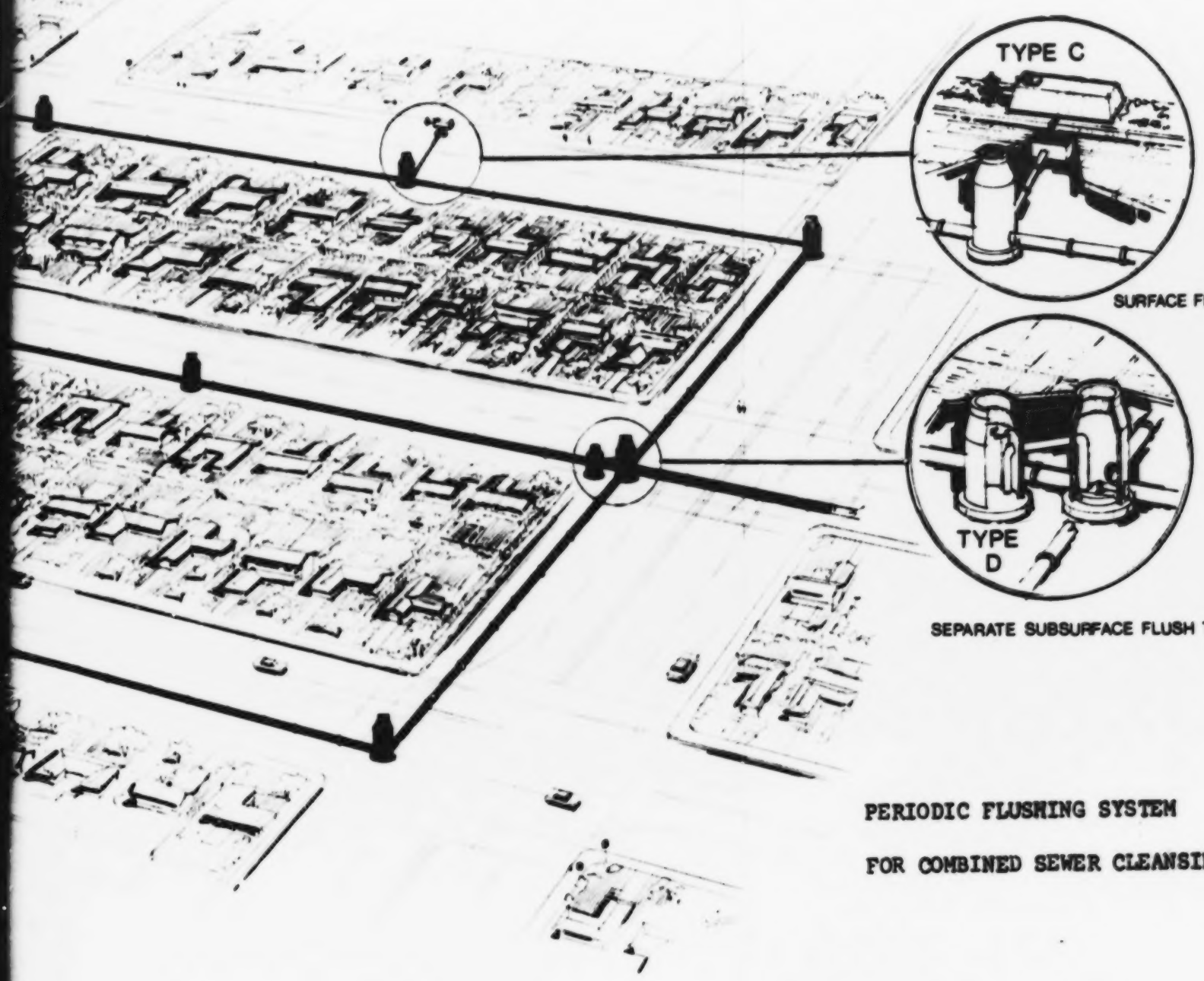

PERIODIC FLUSHING SYSTEM

FOR COMBINED SEWER CLEANSING

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SECTION I

INTRODUCTION

A. Need for Study

The need to minimize pollutional effects of stormwater overflows from combined sewer systems has been documented elsewhere. Even though stormwater provides dilution of sanitary waste, the BOD and suspended solids of the sewage is often very high during storms when flow must be diverted to natural watercourses. The BOD and solids concentration is often particularly high at the start of a storm.

Although the high concentration during the first flush of a storm does not occur at all locations, it does occur frequently enough to be of real concern.

It appears from the available information that a probable cause of a large portion of the high organic load at the start of a storm is the flushing out of solids which had settled in the sewer during dry weather low flow.

B. The Flushing System Concept

A study is being made of the feasibility of reducing the pollutional load of stormwater overflow by periodically flushing combined sewers during dry weather. In order to accomplish the objective of pollution reduction it is necessary for the flushing system to remove that settled material which would be carried away by stormwater flow.

A systematic program of periodic sewer flushing will make it necessary to bypass only that sanitary sewage which is produced during the period of the

storm rather than also bypassing a major portion of the sewage solids produced prior to the storm.

The periodic sewer flushing would be accomplished by a series of flush tanks installed in or next to existing manholes of the combined sewer. These flush tanks would be supplied with strained raw sewage, sewage plant effluent, or other convenient flushing liquid in the manner most appropriate to the conditions of the particular installation. To achieve the proper periodic flushing, the operation of the tanks would be controlled and probably synchronized to flush at specific time intervals. Ideally, the control signals should originate from a single location so that the flushing sequence could be easily changed to accommodate variations in weather and sewage flow.

C. Demonstration Project Plan

The feasibility of a periodic flushing system for combined sewer cleansing must ultimately be demonstrated in an actual combined sewer system. The program leading to the final demonstration has been divided into the following major steps.

Phase I	Study and Planning of the Project and Design of Test Facilities.
Phase II	Determination of Hydraulic Requirements for Flushing Stations and a Control System Required for a Comprehensive Flushing System, Using Test Facilities. Development of Flush Station Equipment.
Phase III	Demonstration of Phase II in a Controllable Portion of a Combined Sewer System.

D. Objectives of This Study

The tasks included in Phase I study just completed were as follows:

1. Further background study, including limited site visitations for investigation of representative past sewer flushing practices.
2. Design of test facilities for determination of hydraulic requirements of a unit flushing system. This will be based upon hydraulic studies as to the range of variation in sewer diameter, slopes and lengths required for comprehensive testing. It is planned to provide representative testing that can be projected hydraulically to provide various manualized directions for application.
3. Design and selection of test instrumentation including sampling equipment and procedure.
4. Development of test procedures.
5. Cost estimates for facilities and testing procedures applying to Phase II.

SECTION II

THE PERIODIC FLUSHING SYSTEM FOR COMBINED SEWERS

A. Studies of Combined Sewage Systems

The consulting engineers, Consoer-Townsend and Associates reported as follows concerning the conditions to be expected in working with combined sewers.

1. Size of Sewer

Normally the minimum size of a combined sewer is 12 inches in diameter. Usually the upper ends of laterals in combined sewer systems will vary from 10 inches to 18 inches in diameter. For testing purposes, an average size of 15 inches is recommended. If a pattern of results between different size sewers is to be established, it may be advisable to obtain experimental data on two different pipe sizes.

2. Velocities and Slope

Today, designers strive to obtain a minimum velocity of 2 feet per second in sanitary sewers and 2.5 feet per second in combined sewers (where allowed) when flowing full or one-half full. Unfortunately, this has not always been true, and parts of many sewer systems operating today were installed at less than minimum grade.

It is important to bear in mind that the velocity of flow in a sewer pipe in which the depth is slight is materially less than when flowing full or one-half full. At one-quarter full, the velocity of flow in the sewer would be approximately 65% of the velocity when flowing full or one-half full.

Previous experiments show that the following velocities of flow are required to move solids:

Kind of Material	Velocity of Flow in Feet per Second
Fine Clay and Silt	0.25
Fine Sand	0.50
Pebbles - Half Inch in Diameter	1.0
Pebbles - One Inch in Diameter	2.0

A velocity of 30 to 40 per cent greater is required to pick up materials than to transport those already in suspension.

It is difficult to obtain adequate velocities of flow in the extremities of a combined sewer system due to flat grades of the sewers and lack of liquid to transport the solids which are discharged into it.

Any test installation or trestle should be so constructed that the slope of the experimental sewer can be varied from 0.1% to 1.0%.

Generally, most combined lateral sewers will have a slope less than 1%, or perhaps even less than 0.5%.

3. Type of Pipe and Joints

A majority of the combined sewers in use today in sizes from 10 to 24 inches were constructed of vitrified clay pipe. Therefore, it is recommended that the experimental sewer be constructed of vitrified clay pipe in the longest lengths available.

A flexible type jointing material is recommended for the test sewer as changes in the sewer slope are in order and some bending of the joint may be required during the changes. Also, the connection and disconnection of the piping would be simpler. The premolded plastic factory-applied ASTM C-425 type joint is recommended.

A number of vitrified clay tees can be inserted into the pipe line so that flows and solids deposition can be observed at regular intervals.

4. Connections for Service Pipes

Service connections from homes to sewers are made by means of wyes or tees usually of 6" branch diameter. The following excerpt gives Consoer, Townsend and Associates Standard Specifications for service connections.

a. General

1. Service connections for house sewer and/or drain connection openings shall be provided in the main sewers as shown on the Contract Drawings or as designated in the Project Specifications. The exact location shall be as directed by the Engineer during construction.

2. Unless otherwise shown on the Contract Drawings or so designated in the Project Specifications all sewer connection openings on bell and spigot pipe shall be "T" branches, with the outlet being six (6) inches in internal diameter. All sewer connection openings on concrete pipe of the tongue and groove type shall be cast in place with the shape, size and dimension of the

opening corresponding to the bell end of a standard sewer pipe six (6) inches in internal diameter.

3. All connection openings shall be closed with a vitrified tile or concrete disk or stopper securely held in place with the same joint material as that specified for the main sewer.

b. Construction

1. All excavation shall be carried out in compliance with the specifications for Excavation, Paragraph C-1.

2. "T" branches for bell and spigot pipe with less than 8 feet from the surface of the ground to the center of the branch shall be laid horizontal with a slight fall across the branch. Connection openings on concrete pipe of the tongue and groove type shall be laid with the opening in the upper quarter of the pipe.

3. When the distance from the center of the connection openings is more than eight feet from the ground surfaces the connection openings shall be raised by means of riser pipes to a point less than 8 feet from the ground surfaces. Pipe risers for single connections shall be laid at an angle of from 45 Degrees to 60 Degrees with the horizontal depending on the side slope of the sewer trench, and shall be laid in undisturbed soil. Pipe risers for double connections shall be installed vertical with a double "T" branch at the top with the branches placed crosswise of the main sewer. All openings shall be plugged with clay or concrete disks. Riser pipes and joints shall be of the same type as specified for the main sewer.

Service connections may also be made in existing sewers by making a hole in the top of the sewer and grouting on a saddle fitting.

5. Junctions Between Sewers

Except in large sewers, manholes are built at all junctions with other sewers. The sewers and their junction are embedded in the base of the manhole up to the spring line or horizontal centerline of the sewers. Then the top half of the clay sewer pipe is broken out to leave a half round trough in the bottom of the manhole. For larger sewers the sewage paths can be formed into the concrete manhole base without the use of clay pipe.

6. Composition of Sewage

Sewage or simulated sewage in the experiment should be as close to that discharged into the extremities of lateral sewers as possible. This sewage would be composed of large solids, including feces, paper and ground garbage. Paper products make up a large percentage of solids in sewage today.

After traveling some distance in sewers, most organic solids are broken down into significantly smaller parts which are more readily transported by sewage. For this reason, sewage from the Brokaw Road sewer may not be typical of sewage found in the upper ends of combined lateral systems. For the purpose of this experiment, it may be necessary to find another source of sewage, such as one of the local lateral sewers from the FMC buildings.

7. Quantity of Sanitary Sewage Flow

Typical 18" Combined Sewer Lateral in Skokie, Illinois

Contributing Area - 10 acres (Residential)

Home per acre - 4.2

People per Home - 4

Contributing Population - 10 x 4.2 x 4 = 168

Flow/Acre/Day x 10 - 100 x 16.8 x 10 = 16,800 gpd

Average Sanitary Flow in 18" Sewer - $\frac{16,800}{1,440}$ = 11.7 gpm

Maximum Sanitary Flow in 18" Sewer (400%) - 11.7 x 4 = 46.8 gpm

Typical Slope 18" Combined Sewer - 0.12% (Minimum due to flat area)

Capacity 18" Sewer @ 0.12% slope - 3.6 cfs or 1600 gpm

Proportional Discharge - $\frac{46.8}{1600}$ = 0.0345 (Maximum)

Proportional Discharge - 11.7 = 0.00732 (Average)

Percentage Depth of Flow -

Maximum - .148 x 18 = 2.66"

Average - .07 x 18 = 1.26"

Minimum - 0 = 0.00"

B. Deposition of Solids in Sewers

1. Literature Reports on Deposition of Solids in Sewers.

The literature was reviewed to find information on deposition of solids in sewers. Raths, C. H. and McCauley, R. F. "Deposition in a Sanitary Sewer" Water and Sewage Works, 1962, shows by experimental results the overriding importance of depth of flow as opposed to slope in transporting

sand through partially full pipes. They also pointed out that pipe joints were largely responsible for starting solids deposition and that close attention should be given to careful construction practices. An article from Public Works Magazine, April 1, 1963, "How Combined Sewer Affect Water Pollution," by Harold Romer and Lester M. Klashman gave the following information on the result of solids deposition in combined sewers.

Combined sewage studies were made in Buffalo, N.Y. in the summer of 1936. On May 24 there was 0.08 inches total precipitation which caused a peak flow rate of more than 40 cubic feet per second in the Albany street sewer where the flow prior to the storm was about 5 cubic feet per second. The suspended solids concentration reached 1550 mg/l when the stormflow was occurring compared to a normal value of about 200 mg/l. This rainfall was preceded by five dry days and resulted in the discharge of solids present in a 1 1/2 day normal flow of raw sewage.

At the same location a storm on July 23 caused 0.21 inches of rain. The peak flow was more than 120 cubic feet per second and the peak suspended solids was 5000 mg/l. This rainfall was preceded by 26 dry days and the suspended solids discharged was equal to the solids present in a 7.8 day flow of raw sewage.

The following observations were made when an abandoned quarry was used as a storage basin in Buffalo, N. Y., to relieve the combined sewer system during the periods of rain. The weirs were set to allow overflow into the quarry at a rate of 20 times average dry weather flow. Using

conventional methods for such calculations, the amounts of organic matter likely to settle in the storage basin during and after storms of various intensities and durations were estimated. The estimated amounts were all extremely small. It was seen, however, that fifty times the estimated amount of sludge had settled on the bottom of the basin when this was emptied after having been in operation for the first time.

2. Sewer Inspections

On March 28 and 29th, inspections were made by J. P. Pelmulder and Consoer, Townsend representatives of combined sewers in Hammond, Indiana and Park Ridge and Skokie, Illinois. The sewers chosen for inspection were the head ends of laterals in generally flat terrain in neighborhoods with large lot, single family homes; small lot, single family homes; multiple family dwellings; and light industrial businesses.

It was noted that there were usually small non-uniformities of slope at manholes so that it was generally necessary to look a short distance into the sewer to determine its typical condition. Mortar protrusions at the joints and buildup of growths because of infiltration at the joints were also noted. However, the most serious hindrance to free flow of the sewage and full removal of sewage solids was the general prevalence of sand and gravel forming a flat bottom in the sewers and the frequent occurrence of other debris. Where manholes were made of brick there was high frequency of parts of bricks in the sewer. In other cases, sticks, rocks, and pieces of clay pipe were observed

in the sewer. In two cases the first sewer chosen in an area proved to be partially blocked as evidenced by being full to 1/2 depth or more with no noticeable flow. In those two cases, another nearby sewer was chosen for inspection. These sewers had recently carried runoff from light rains and melting snow but there had been no heavy rains since the previous fall.

With the low flow prevailing during the inspection there was generally some paper and light solids on top of the sand and gravel in the bottom of the sewer.

One design practice which almost invariably caused separation and deposition of solids was the connection of household service connections into the side of a manhole. Where the sewage flow fell onto the floor of the manhole, rather than into the sewer channel, separation of solids naturally occurred.

The condition of the combined sewers which were inspected would not be typical of sewers in a system where a periodic flushing system has been installed. In order for a periodic flushing system to be effective, the large accumulations of sand and gravel would first have to be removed from the sewers and disintigrating brick manholes would have to be repaired to prevent debris from getting into the sewer. Then use of the flushing system should prevent sand and fine gravel from sticking together and forming large accumulations of pollutional solids in the sewer which would be difficult to flush out. Thus the periodic flushing system should only have to

contend with the solids which have been stranded in the sewer since the last flush occurred.

In addition, there might be a small amount of gravel and larger rocks which would not be removed by flushing. One of the things which must be determined in Phase II of this program is whether pollutional materials can be flushed out of the sewer even though some rocks or gravel remain in the sewer.

C. Studies of Sewer Flushing

1. Hydraulic Theory

The problem of flushing sewers falls into the category of unsteady flow in partially-full circular conduits. Theoretical solutions for for the depths and velocities of waves are extremely tedious because of the effect of the changing shapes as the depth varies in the circular cross-section.

Methods used to predict the depth, velocity, and flow rates of waves moving through circular pipes were reviewed with Professor A. H. Barnes at Colorado State University. Professor Barnes has developed a computer program solution to the continuity, momentum, and friction equations for unsteady flow and has compared this solution to experimental results obtained in a 3 foot diameter pipeline which is 825 feet long. It was found that the leading face of the waves was generally quite steep and the trailing side was much more moderately sloped. These studies and experiments were financed by the Bureau of Public Roads and have not been published yet.

Professor Barnes has offered to work as a consultant to calculate unsteady flows for any condition of interest for this program and to modify the computer program to represent the conditions of sewer flushing. Such computer prediction correlation of unsteady flow would be of value in the sewer flushing test program.

2. Literature Reports of Flushing Tests

The most complete report of sewer flushing tests which was found in the literature was H. N. Ogden, Trans. of the ASCE, 1898, Flushing in Pipe Sewers. This was a report of the results obtained in flushing eight inch sanitary sewers of various slopes. Additional information on the application of flush tanks was found in textbooks of the same era. These references indicated that a single flush tank can remove sediment from 600 to 800 feet of sewer with the quantity of flushing water required varying inversely as the slope of the sewer. A more recent reference, Sewer Flushing, J. D. Watson, Water Works & Sewage, Vol. 84, August 1937, indicates that flushing tanks can be effective for distances on the order of 1/2 to 1 mile if slopes are adequate and flush water quantities are as large as 2000 or 3000 gallons.

Some observations made from the literature studies are that the condition during flushing where the sewer flows full and the flushing wave moves through the pipe like a piston is not likely to exist for a very long time before the head losses exceed the slope and pressure head available. Therefore, the sewer will generally flow partially full for most of the length between flush tanks. In the case where the sewer is flowing partially full, the velocity of the

main body of the flushing wave will be largely determined by the depth of flow and the slope of the pipe. The effect of the level of sewage flow prior to flushing is somewhat uncertain. Because of the low momentum of the slowly flowing sewage, it is likely that it would tend to retard the high velocity, piston-like flow near the flush tank and would probably reduce the velocity of flow at the leading edge of the flushing wave. However, by raising the level in the sewer during flushing, any flow prior to flushing should tend to increase the velocity in the main body of the flushing wave and to extend the distance over which a high velocity is maintained.

Opinions expressed in the literature credit the velocity at the leading edge of the flushing wave with being responsible for dislodging any accumulation of solids and for scouring the pipe. The velocity of the main body of the flushing wave is considered to be responsible for carrying solids through the pipe. Since this velocity is limited by the slope of the sewer for most of the length between flush tanks, the size of the gravel which can be removed will be limited accordingly.

3. Flushing Tests by FMC Corporation

During the field inspections of combined sewers a brief experiment was made to determine the ease of removing deposited solids. At two locations a 2" or 3" hose was used to increase the flow and partially flush the sewer. This was effective in removing the paper and light solids and some sand but did not remove heavy accumulations of sand and gravel.

The increase in flow only resulted in the sewers flowing approximately one quarter full or less. Thus it is seen that that the large sewage solids to be found in sewer laterals will not be difficult to flush out but that sand and small size pollutional solids mixed with sand will be the most difficult to remove.

Further preliminary flushing tests were conducted at Central Engineering Laboratories using an existing eight inch diameter clear plastic pipeline. The total pipeline length was 71 feet and it was set at a slope of 0.38%. It was found that any sediment could be flushed out of this short length of pipe using ten cubic feet or less of flush water. It was noted that a smooth, continuous layer of sand in the invert of the pipe was very difficult to pick up because of the laminar film established over it even at high velocities of flow. Single larger pieces of rock were removed much more quickly and with less water than the smooth layer of sand.

The preliminary flushing tests were conducted as follows:

Apparatus

Flush tank - 42 cu. ft. capacity.

Orifice to sewer pipe - 4" I.D. with air activated power operated butterfly value (activation time = 1.5 seconds).

Sewer pipe line - 8" I.D. with 23' of steel pipe and 48' of acrylic plastic pipe (grade = .38%) supplied with raw sewage.

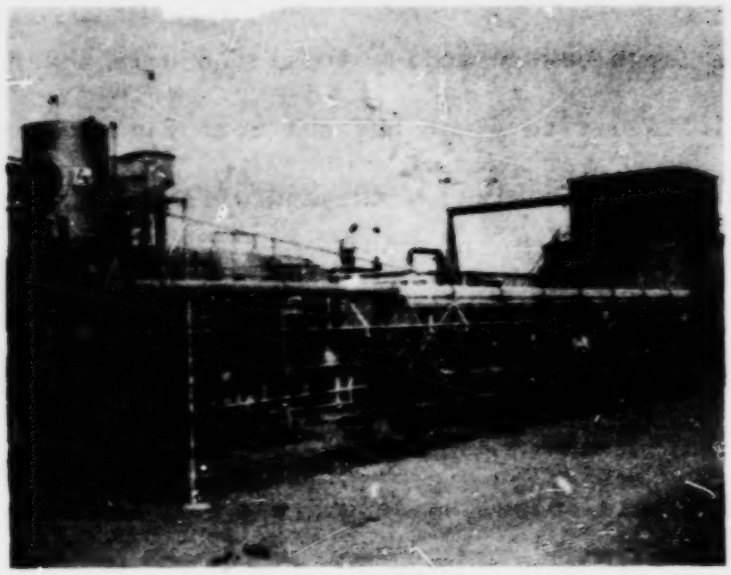


Figure 1

Flush Tank and 8"x71' Sewer Pipe

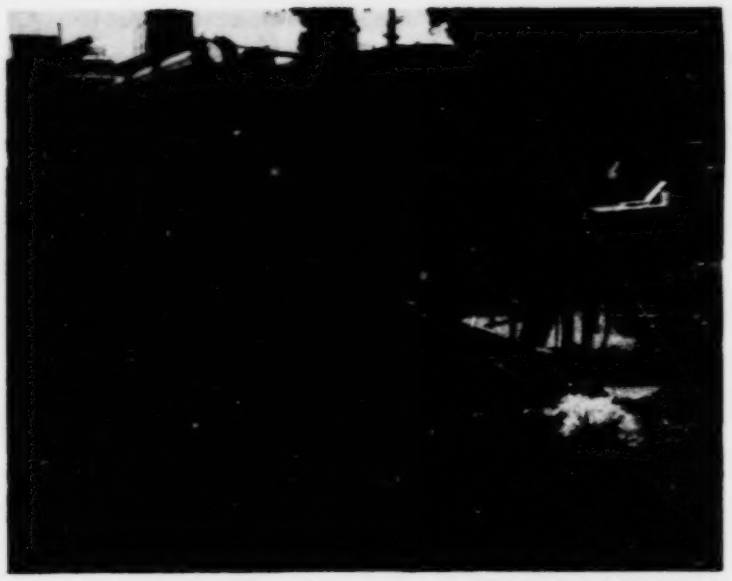


Figure 2

Catch Basin With Diverter and Scale Setup

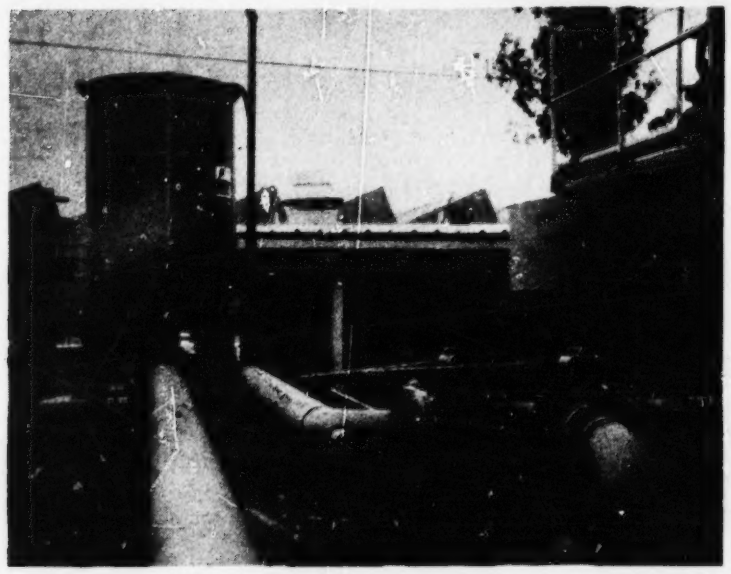


Figure 3

Raw Sewage Line Connecting With
Flush Tank and 8" Sewer Pipe

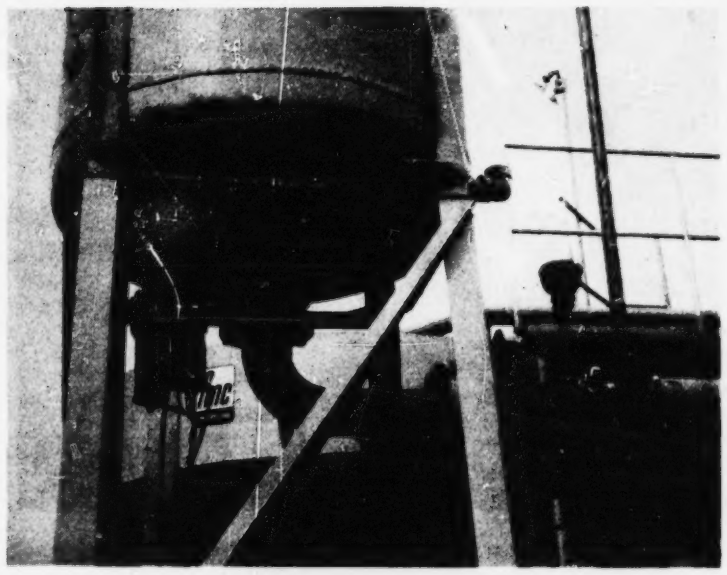


Figure 4

Flush Tank With Power
Operated Flush Valve

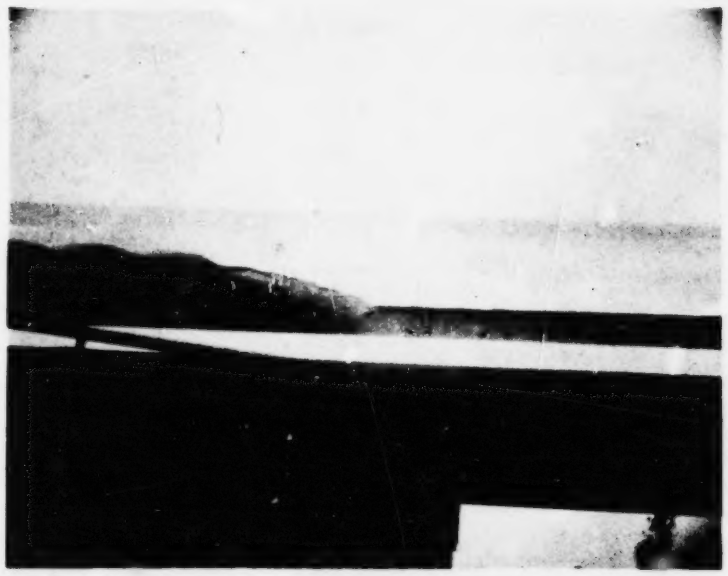


Figure 5

Typical Flush Wave
Sewage Flow Interface

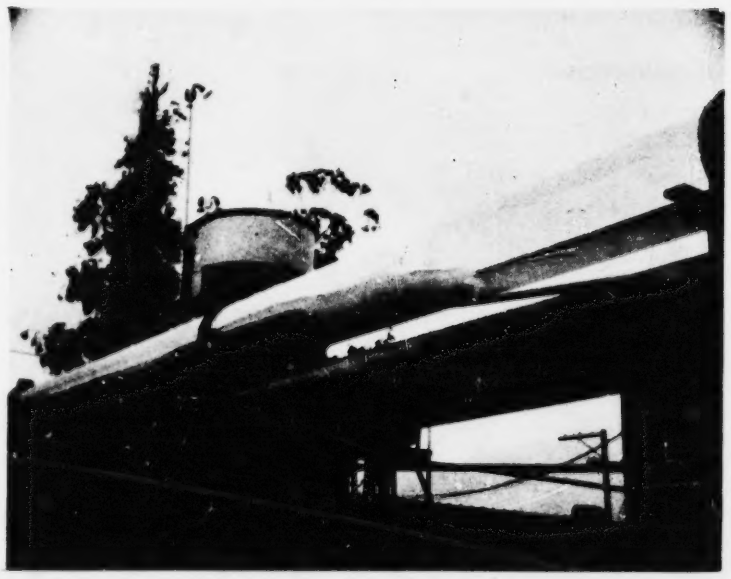


Figure 6

Flush Wave Showing
Steep Wave Front

Catch basin - includes weir box and diverter which diverts flow to either the city sewer system or a weighing tank used in determining flow rates.

Operational and Data Collecting Procedure

(a) Fill the flush tank to a prescribed level.

(b) Activate the flush valve for a prescribed duration giving the "flush time".

(c) Time the arrival of the flush wave at prescribed distances along the sewer pipe.

(d) Note the wave height and the area of the flush wave most active in sediment transport.

(e) Note the distance of sediment transport.

(f) Note the new level of the water in the flush tank giving the cubic foot volume of the flush wave.

Four runs were made with a 2 second, 4 second, 6 second, and 10 second flush duration at each of the following head levels in the flush tank under two different sets of conditions (I & II):

(a) 75"

(b) 68"

(c) 55"

(d) 41"

Condition I - no sewage flow.

Condition II - 12-14% depth of sewage flow.

Flush Wave Phenomena Observed (Figs. #5-11 show various flush wave characteristics).

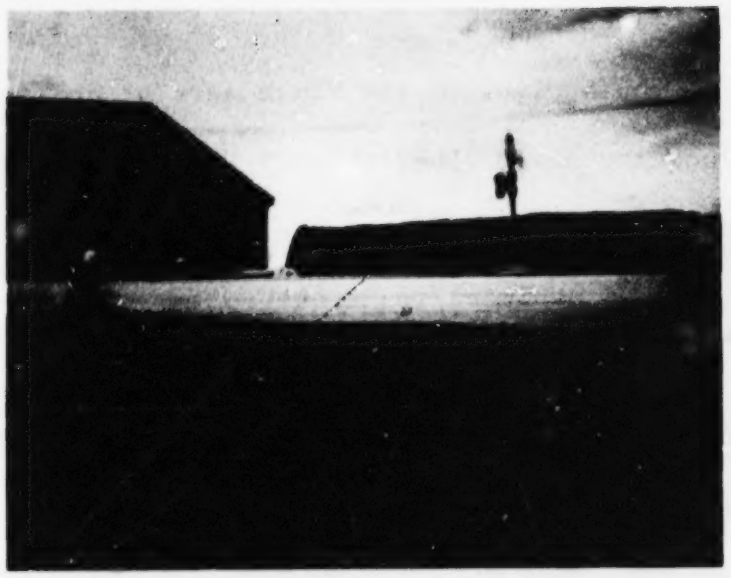


Figure 7

Flush Wave With Sediment Carried
Behind Wave Front

(a) An increased head in the flush tank results in a

1. greater discharge rate,
2. faster wave velocity,
3. greater wave height.

(b) An increased flush duration results in

1. more cubic feet of water in the wave.
2. a greater wave length,
3. a greater wave height.

(c) "Surging" - an alternating increase and decrease in the wave front velocity as smaller waves reinforce the main wave.

1. is more prevalent in tests without a sewage flow than in tests with a sewage flow
2. in both cases, with and without sewage flow, the "surging" is greater with increased flush durations.

(d) The initial 12" - 18" of the wave, in some instances, appears to ride on top of the sewage flow leaving the remainder of the wave to mix and transport the sediment.

(e) A 6 second flush duration was more effective for scouring and transporting of sediment than either a 2 second or a 4 second flush and was equally as effective as a 10 second flush for this length of pipe.

(f) Wave reinforcement - a series of two 3 second flush waves was more effective than either, one 6 second flush, or three 2 second flushes, for scouring and sediment transport in this length of pipe.

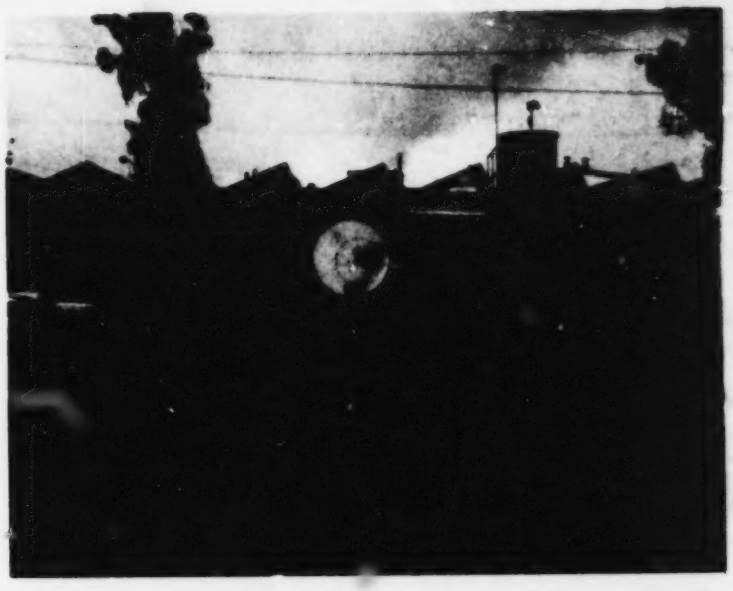


Figure 8

8" Sewer Pipe With 3/4" Polyethylene
Tubing Simulating Supply Line

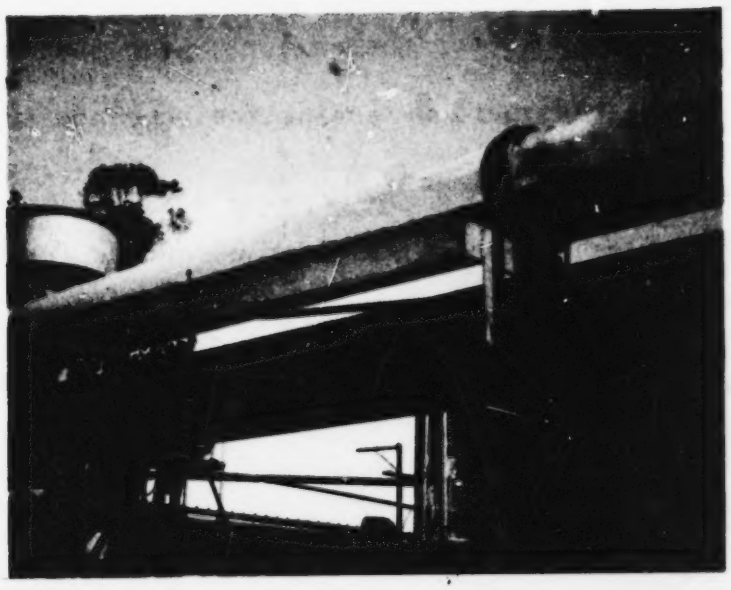


Figure 9
Flush Wave With 3/4" Supply
Line In 8" Sewer Pipe

Figure 10

8" Sewer Pipe Containing 3/4" Supply
Line With Sediment Before Flush

Figure 11

8" Sewer Pipe Showing Absence of Sediment
And Supply Line Raised By Flush Wave

TABLE # 1 - FLUSH WAVE VELOCITIES WITH 12-14% SEWAGE FLOW

Run #	Begin Level (Cu.Ft)	End Level (Cu. Ft)	Cubic Feet Released	Flush Time (Secs)	Wave Height (Ins)	23' E.T. (Secs)	23' V. (Ft/sec)	35' E.T. (Secs)	35' V. (Ft/sec)	47' E.T. (Secs)	47' V. (Ft/sec)	59' E.T. (Secs)	59' V. (Ft/Sec)	71' E.T. (Secs)	71' V. (Ft/sec)	Ave. V. (Ft/sec)
26	36	35	1	2	3.5	4.7	4.89	6.8	5.15	8.8	5.34	11.2	5.27	14.2	5.00	5.00
28	30	29	1	2	3.5	4.8	4.79	6.8	5.15	9.0	5.22	11.4	5.18	14.7	4.83	4.83
30	20	19	1	2	3	5.1	4.52	7.0	5.00	9.1	5.17	11.5	5.13	15.0	4.73	4.73
32	10	9	1	2	3	5.2	4.43	7.2	4.86	9.4	5.00	12.0	4.92	15.3	4.64	4.53
34	35	33	3	4	4	4.7	4.89	6.4	5.47	8.2	5.73	10.0	5.90	12.5	5.68	5.68
36	30	27.5	2.5	4	4	4.7	4.89	6.7	5.23	8.4	5.59	10.2	5.78	12.8	5.54	5.55
38	20	17.5	2.5	4	3.5	5.0	4.60	6.8	5.15	8.8	5.34	10.6	5.57	13.1	5.42	5.42
40	10	8	2	4	3.5	5.2	4.43	6.9	5.07	9.0	5.22	11.0	5.36	13.8	5.14	5.15
42	35	31	5	6	4	4.8	4.79	6.2	5.54	8.3	5.66	10.0	5.90	12.1	5.87	5.87
44	30	25	5	6	4	4.8	4.79	6.3	5.56	8.4	5.59	10.3	5.73	12.4	5.72	5.73
46	20	16	4	6	3.5	4.9	4.69	6.5	5.38	8.9	5.28	10.8	5.47	13.2	5.38	5.37
48	10	7	3	6	3.5	5.2	4.43	6.7	5.23	8.9	5.28	10.9	5.42	13.5	5.26	5.25
50	36	27	9	10	4.5	4.7	4.89	6.1	5.73	8.3	5.66	10.1	5.84	12.2	5.82	5.82
52	30	21.5	8.5	10	4.5	4.7	4.89	6.3	5.56	8.4	5.59	10.1	5.84	12.6	5.63	5.63
54	20	13	7	10	4	4.8	4.79	6.3	5.56	8.8	5.34	10.6	5.57	13.1	5.42	5.42
56	10	5	5	10	3.5	5.1	4.52	6.8	5.15	9.1	5.17	10.9	5.47	13.5	5.26	5.25

* Distances are measured in feet from the flush tank orafice
E.T. = Elapsed Time V. = Velocity of Flush Wave

36 cu. ft. = 75" head
30 cu. ft. = 68" head
20 cu. ft. = 55" head
10 cu. ft. = 41" head

(g) When 71' x 3/4" polyethylene pipe was placed on the invert of the 8" sewer pipe and filled with water, no increased difficulties were encountered with sediment removal. It was observed that the polyethylene pipe raised off the invert during a flush. (Fig. #11)

Reference to Sewage

(a) The sewage flow used in the testing procedures approximated 12-14% by depth in the 8" sewer pipe and resulted in a 1.1 ft/sec flow velocity and 8.5 gal/min. flow rate.

(b) With the above sewage flow a flush wave was slowed approximately 9-10% with a velocity of 5-6'/second, as compared to a flush wave with no sewage flow.

(c) With the testing setup employed, no appreciable difference in the efficiency of sediment removal could be detected when comparing a flush with a 12-14% sewage flow and a flush without the sewage flow

4. Application Criteria for Flushing Combined Sewers

Flushing systems of the kind under study would be more useful in some situations than in others. Flushing probably would be most useful on small lines of flat to moderate slope.

As the sewer line size increases the quantity of flush water required will also increase and the flushing process will eventually become uneconomical because of high water consumption and the large flush tank required. Likewise the cost will be greater where extremely flat grades are encountered because the required flush volume will be greater. However, the need for flushing would be greatest with flat slopes.

At the other extreme there will be sewers with great enough slopes and flow rates so that solids deposition will be a minor problem and flushing would not significantly increase the sewer cleanliness .

The suitability of sewer flushing would also be dependent on the concentration and characteristics of solids present, on the dry weather flow rate, and on the stormwater frequency and flow rate.

D. Studies of Sampling Methods and Equipment

1. Field Sampling Problems

The objective in field sampling is to obtain at any given time a representative sample of sewage from a sewer line. Sewage is a heterogeneous mixture of coarse and fine suspended matter and grit or sand-like particles.

Since sewage is a heterogeneous mixture of particles with varying densities, the higher density material, such as sand and grit flows along the bottom of the pipe, as seen in the clear plastic pipe. Consequently, sampling at any one point in the sewer will not necessarily give a representative sample of the sewage.

Another problem is that the grit flowing on the bottom of the pipe has a tendency to settle out during low flows.

A third problem is the variation in the flow rate of the sewage. Consequently, samples must be taken in proportion to the flow rate of the sewage. Thus, samples need to be taken more frequently at high flow rates than at lower flow rates.

In order to take a representative sample of raw sewage, the sample should be taken in an area where there is good mixing. However, grit and sand like material are very difficult to mix completely. A cross sectional sample can be taken with a Trebler Scoop if the flow is not well mixed.

2. Available Sampling Equipment

Where the sewage flow falls a small distance such as over a weir or into a drop manhole the mixing would be reasonably thorough and sewage could be drawn into a pump for delivery to a sampler.

In cases where no fall is available to agitate the sewage an external source of power would be needed to do the mixing. This might take the form of a rotary or reciprocating mixer, a pump recirculating part of the stream, or diffusers bubbling compressed air through the sewage to supply mixing and prevent segregation of different types of material.

From such a mixed area, the sewage would be pumped to the sampling device. A strainer on the suction of the pump would prevent large solids from clogging the pump or sampler. The strainer would be kept clean by backflushing after every sampling cycle.

Once the sample has been removed from the sewage line, a proportionating device can be used to sample. There are many proportionating devices available, such as Chicago Pump's "Tru-Test" Sampler.

3. Flushing Evaluation Sampling Problems

In the flushing evaluation tests of Phase II it is desired to determine the ability to clean pollutional materials from a combined sewer with various types of flushes. The efficiency of the cleaning process should be based only on that pollutional materials which would be removed from the sewer by stormwater flow. Since it is impractical to construct a test sewer of variable length, it is highly desirable to determine the cleaning efficiency versus length in a test sewer which is too long to be completely flushed under the conditions of the tests.

In order to determine the cleaning efficiency, it is necessary to know two of the following three items:

a. The amount of pollutional material in the sewer before flushing

b. The amount of pollutional material removed from each section of pipe by the flush wave.

c. The amount of pollutional material remaining in each section of pipe after flushing which would be removed by subsequent stormwater flow.

Several different means were considered for gathering this information.

The tee openings at intervals of 18 feet are available for inspection, measurement, or sampling. It is considered impractical to take samples from a moving flushwave which represent the materials carried by the flush wave as it passes several points along the test sewer. However, the tee openings can be used to visually inspect the quantity and type of sediment remaining in the test sewer when there is no flow.

In the flushing evaluation equipment, access to the interior of the sewer is available every 18 feet. This will provide direct access to over 5% of the length of the test sewer. It should be possible to inspect several feet in either direction from the tees by use of lights and mirrors. This should provide a view of a large enough portion of the length of the line to give a good indication of the location of sediment either before or after flushing.

Several methods were considered for determining the sediment distribution along the test sewer.

Commercial equipment is available to take stereo photographs of sewers and to take television pictures of sewers for showing on closed circuit monitors. Both of these methods would normally require dragging cables through the sewer line to operate the cameras. The cable would disturb the sediment deposited in the sewer and preclude any further measurement of sediment location or entrainment in stormwater flow. For our purposes a closed circuit TV camera could be devised to examine the short lengths of sewer between tees with the cables held above the invert of the sewer so as to avoid disturbing the sediment.

Another method considered was the use of radioactive tracers or natural radioactive ores to be counted by a radiation detector either moving through the pipe or moving along a rail external to the test pipe. All of these methods have the disadvantage that they do not measure the variable of real interest, that is BOD and SS which would be removed by stormwater flow and would have to be correlated to give results in terms of these variables. The correlation becomes a research

project almost of the same magnitude as sewer flushing. The majority of these methods would require pulling cables through the sewer which would be very cumbersome. The use of artificial radioactive tracers would require recovery of all radioactive materials before the sewage is returned to the city sewer.

The testing and sampling procedure finally selected for use in the flushing evaluation tests is as follows:

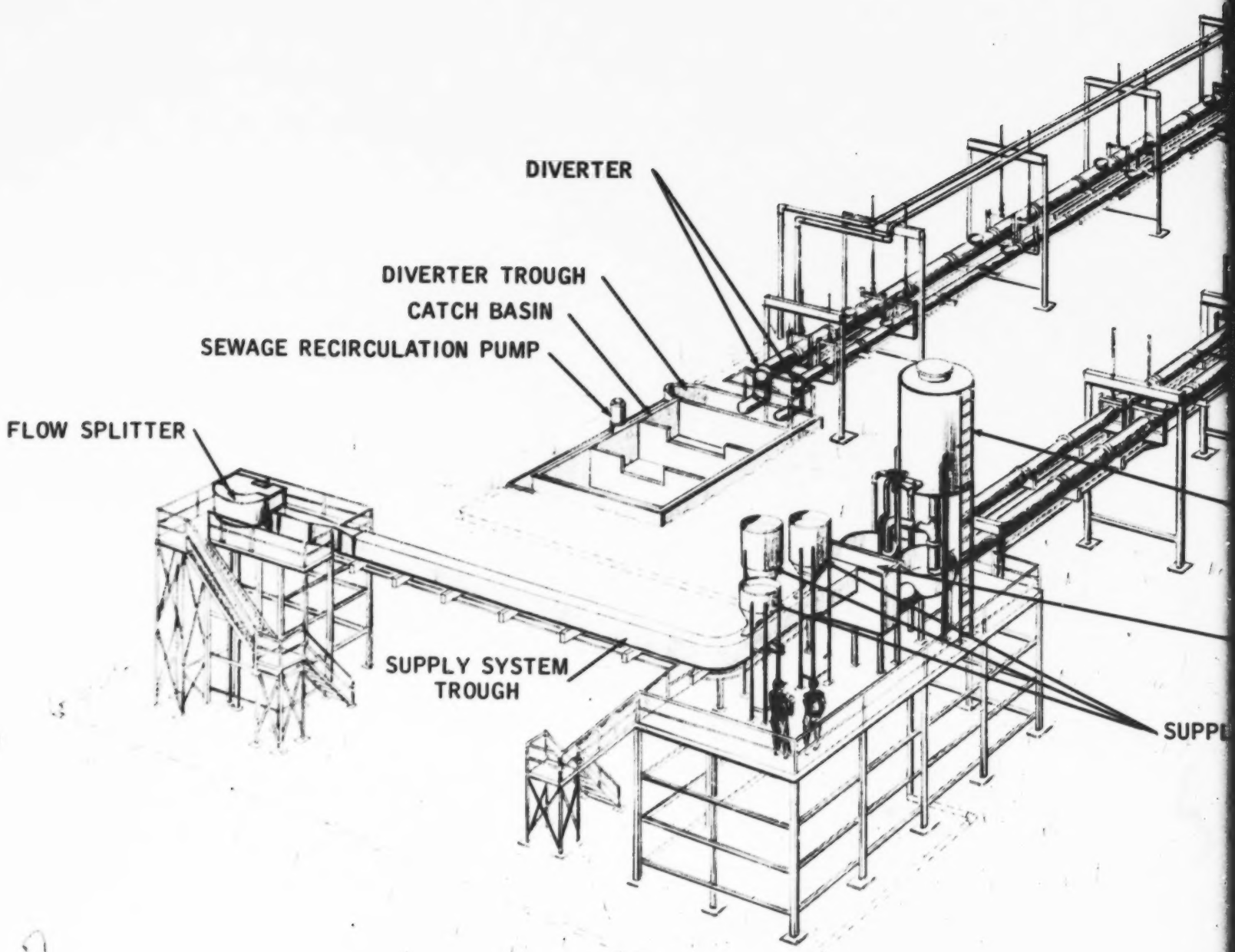
a. Run sewage through the test sewer for one day less the testing time. Add additional sewage solids if necessary. This must be done in a repeatable manner to uniformly distribute the deposited solids in the test sewer. The uniformity of deposition will be verified by inspection through the tee connections. The quantity of solids in the test sewer will be estimated from the quantity and strength of sewage flowing into the test sewer, the quantity and type of supplemental solids added, the quantity and strength of solids retained in the catch basin at the discharge of the test sewer, and the strength of the sewage discharged from the test sewer. These quantities can be correlated with the solids remaining in the sewer when the test sewer is washed by a simulated storm-water flow as will be described presently.

b. Release the flushing wave. Measurements which will be taken during flushing are flush tank level recording, liquid level recording from test sewer at three points, and sample of flush tank water (unless it is from a known, uniform quality supply). The flush wave will be observed through port holes in the test sewer. The

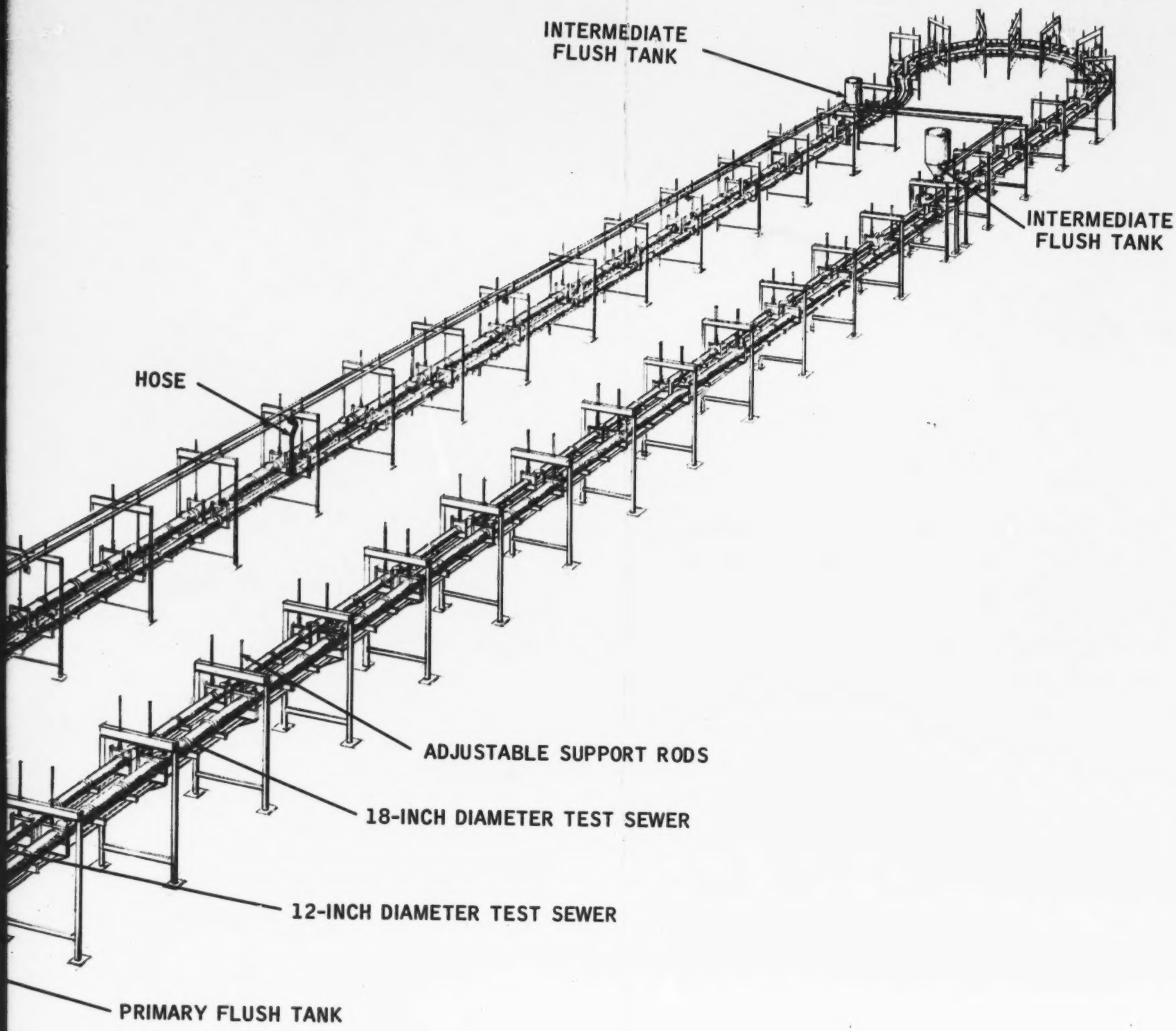
flush wave will be collected in the catch basin at the discharge of the test sewer, the contents of the catch basin will be mixed by a power mixer and a sample will be taken which is representative of the entire contents of the flush wave. The interior of the test sewer will be inspected through the tee openings to determine the approximate degree of cleaning which has been performed at various distances from the flush tank. Samples of the sediment will be taken by hand through the tee openings if it is considered worthwhile.

c. Start the simulated stormflow in the section of test sewer following the last section which was effectively cleaned by the flush wave. Starting with a clean catch basin, add clear water to the system and recirculate through the test sewer starting at the last section of interest. The simulated stormflow must be at the proper velocity to remove pollutional materials from the test sewer to the same extent that stormflow would remove pollutional material from an actual combined sewer. Measurements taken will be beginning and ending BOD and SS, liquid levels in the test sewer and the catch basin and flow rate. From these data the number of pounds of BOD and SS removed per foot of sewer by the simulated stormflow will be calculated.

The same procedure of applying a simulated stormflow will then be repeated for each section of test sewer working toward the flush tank and the BOD and SS removed by the flush wave will be calculated for each length of test sewer.

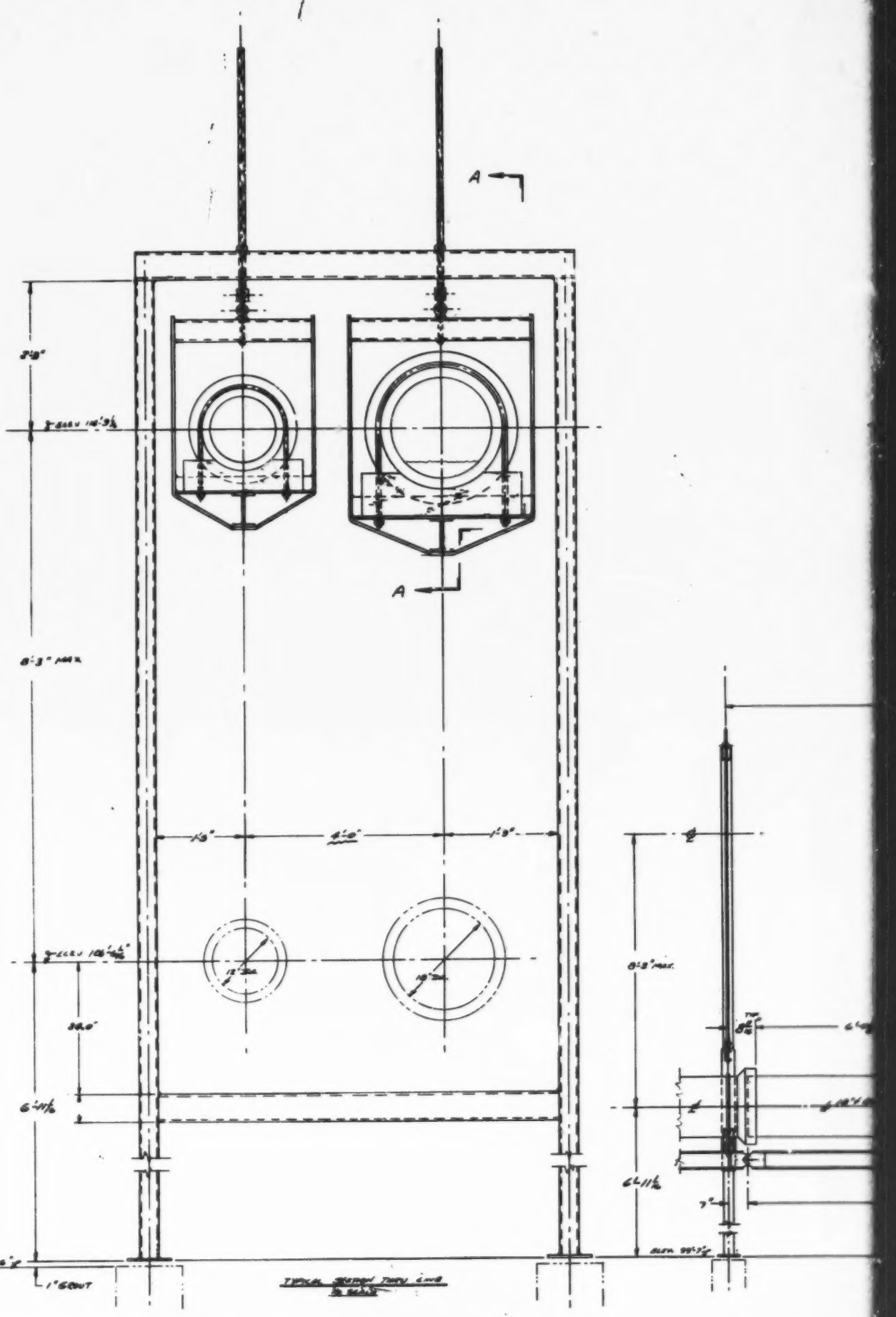

DIVERTER
DIVERTER TROUGH
CATCH BASIN
SEWAGE RECIRCULATION PUMP
FLOW SPLITTER
SUPPLY SYSTEM TROUGH
SUPPL

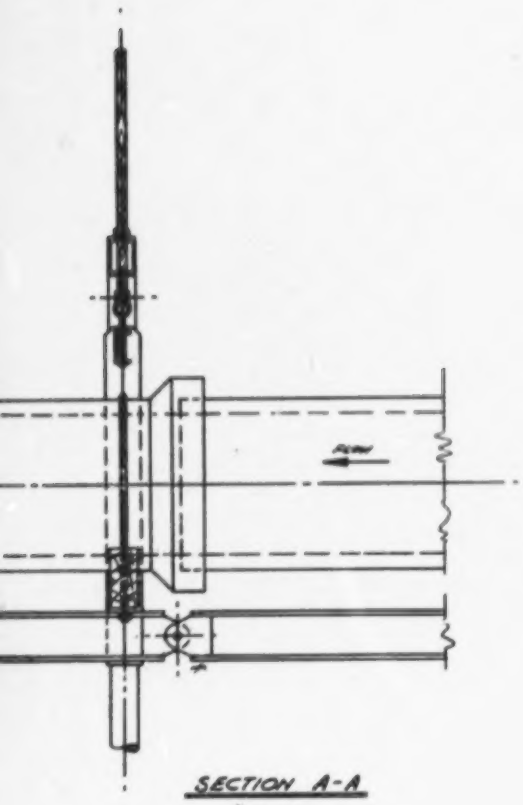
A



B

PROPOSED FLUSHING EVALUATION SYSTEM


A
A
8'-3" MAX.
1'-9"
4'-0"
1'-9"
38.0"
6'-11½"
8'-3" MAX.
GL 99'-6½"
1" GROUT
GL 99'-7½"
7"
GL 11½"



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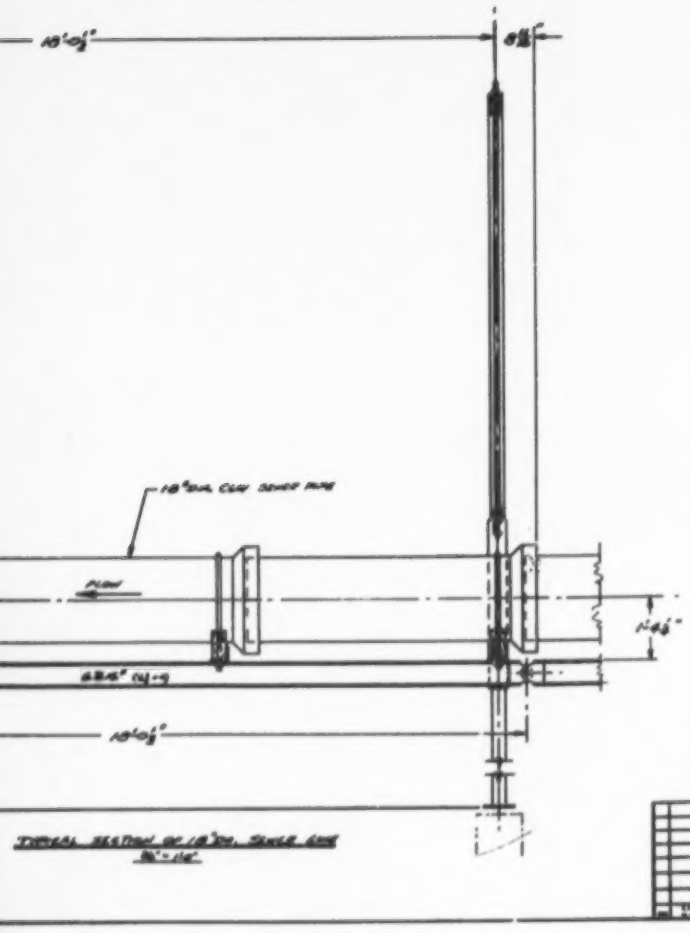
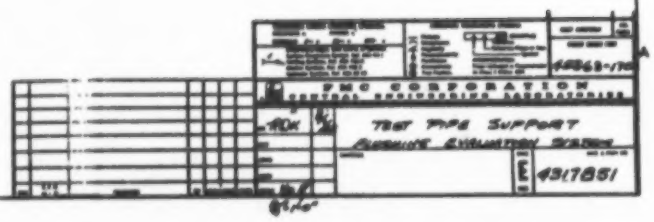
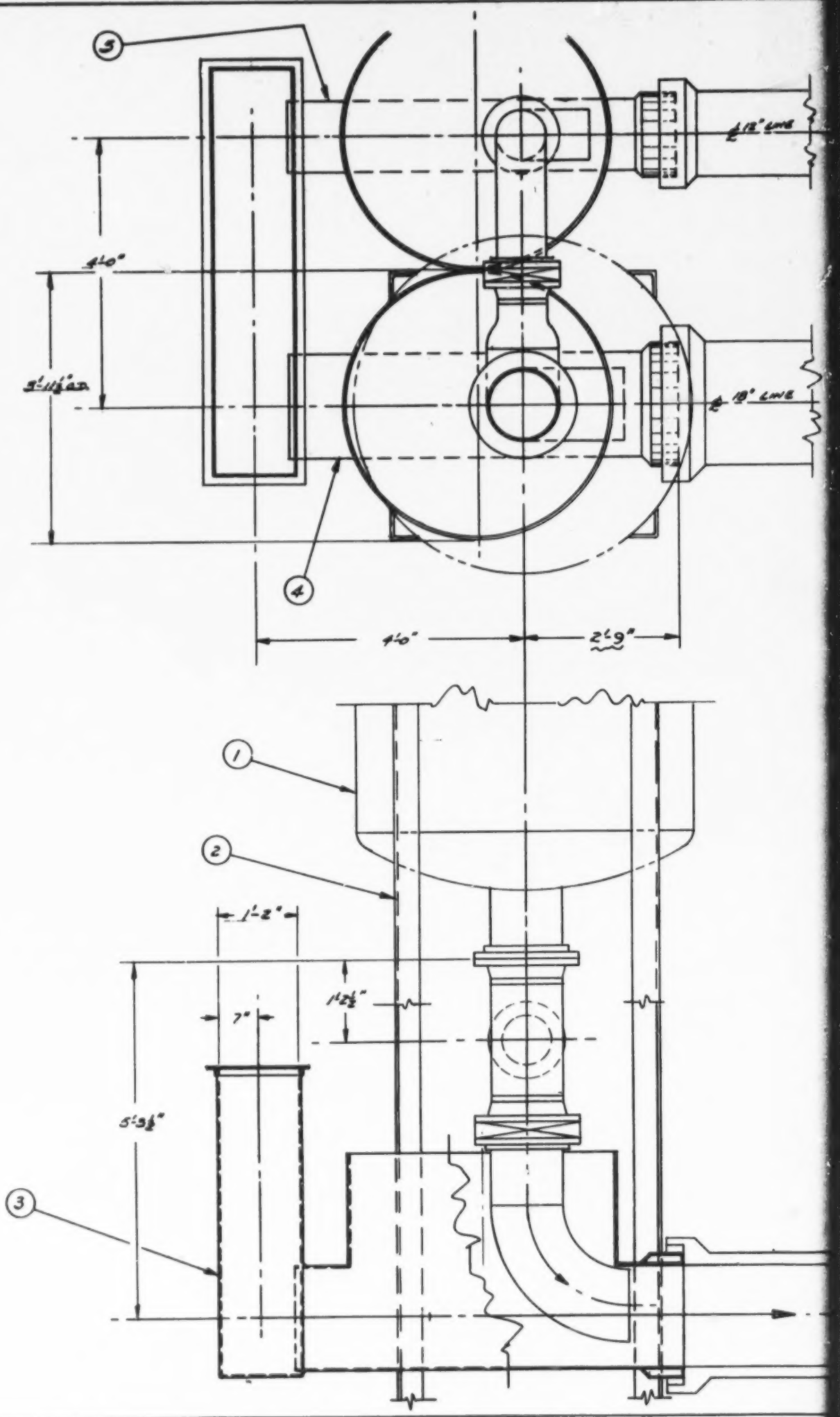


TYPICAL SECTION OF 18" DIA. SEWER LINE

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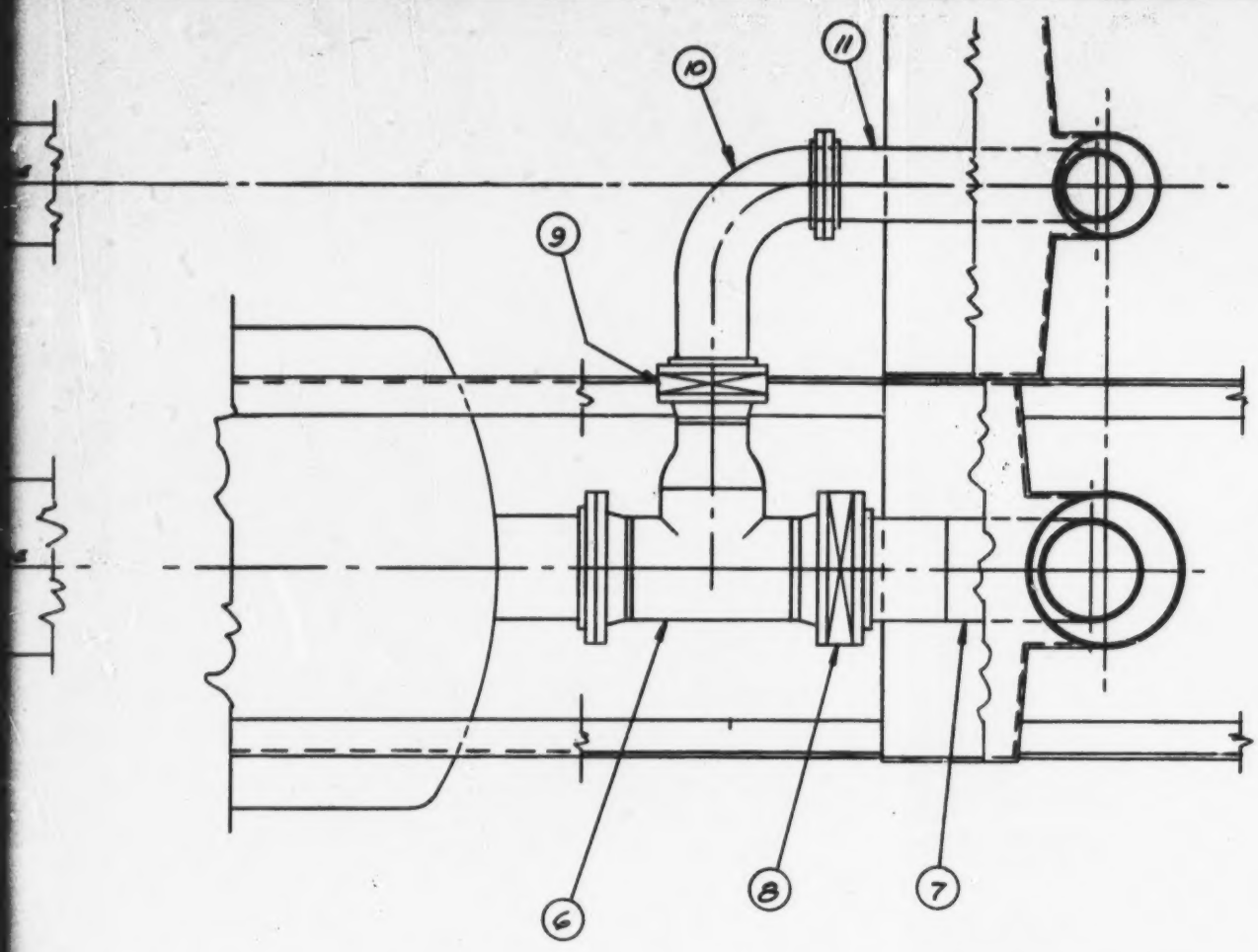
4'-10"
5'-11½"
4'-0"
2'-9"
1
2
1'-2"
1'-2½"
7"
5'-3½"
3



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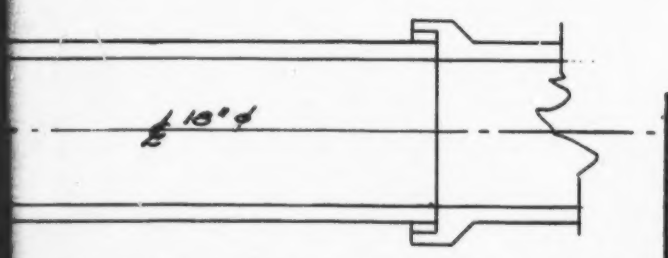
2		1		SUPPORT FRAME
3		1		DIVERTER
4		1		MANHOLE - 18" LINE
5		1		MAN HOLE - 12" LINE
6		1		12" PIPE WELDMENT
7		1		12" PIPE WELDMENT
8		1		12" WECO BUTTERFLY VALVE (175 PSI)
9		1		8" WECO BUTTERFLY VALVE (175 PSI)
10		1		8" PIPE WELDMENT
11		1		8" PIPE WELDMENT

B



TOTAL REQ'D 1 | E4317900 | 1

45363-17 A

FMC CORPORATION
CENTRAL ENGINEERING LABORATORIES

R.O.K. 4/1/62

PRIMARY FLUSH TANK PIPING
FLUSHING EVALUATION SYSTEM

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E. Design of Flushing Evaluation Equipment

1. Requirement for the Flushing Evaluation Equipment

From the statement of the sewer cleansing problem and the foregoing background studies, it follows that certain information must be determined by experiment in order that a sewer flushing system may be applied to an actual combined sewer system. The experimental information which is needed is how much pollutional material can be removed from a sewer by flushing with a given quantity of water for a particular slope, diameter, and length of pipe. Additional variables which must be investigated are effect of flushing discharge rate, effect of existing level of flow in sewer, effect of changes in slope, diameter or other physical features, and effect of reinforcing flush waves released from succeeding flush tanks along the length of the sewer.

To accomplish these tests, equipment is needed with at least two diameters of sewer pipe having an adjustable slope and a means of comparing the cleaning effect of the flush wave with the cleaning effect of storm flow.

2. Design Concept

The general layout of the proposed flushing evaluation equipment is shown in Figure 12. Raw sewage will be supplied to the flushing evaluation equipment from the Hydroscience Facility wet well and pump pit through the 6-inch vertical sewage supply pipe at the left of the illustration. The sewage flows up the pipe and into the flow splitter where it flows over a weir and onto the splitter vane. A portion of

the sewage flows out of the flow splitter and through a 3-inch Parshall Flume. An instrument at the flume senses the level of the sewage, records and totalizes the sewage flow rate, and sends a pneumatic control signal to an actuator connected to the splitter vane to keep a constant flow rate. The portion of the sewage flow which is not directed to the flume is wasted through the other vertical 6-inch pipe. A sampler would be connected at the flow splitter so as to recieve well mixed sewage.

From the Parshall Flume the sewage flows through the overhead trough to the platform at the head end of the test sewers. At this platform additional solids can be added to the flow from these elevated tanks. The solids to be added would be sand, raw sewage sludge, and paper.

The flow is next divided between the 12-inch diameter test sewer. At the start of each test sewer is a metal representation of the lower portion of a manhole. The test sewers themselves consist of vitrified clay pipe sections joined with preformed factory applied plastic joints. The straight portions of the test sewers are supported by 18-foot long I-beams which are hinged together and supported by threaded rods from overhead crossbeams. The elevation of the pipes and thus the slope can be adjusted by turning the nuts on the threaded support rod.

A pipe support I-beam with a greater moment of inertia has been substituted for the one appearing on the drawings.

The original design used a 6-inch light beam with a weight of 16 pounds per foot. The deflection would have been:

$$\Delta \text{ max} = \frac{5\ w\ l^4}{384\ EI} = \frac{5 \times (257/12) \times (18 \times 12)^4}{384 \times 30 \times 10^6 \times 31.7} =$$

$$\frac{20.25}{31.7} = 0.64 \text{ inches}$$

This would have been excessive.

The revised design will use a 12" x 4" light beam with a weight of 19 pounds per foot.

The deflection at the center of the span with the 18" pipe full of water will be:

$$\Delta \text{ max} = \frac{5\ wl^4}{384\ EI} = \frac{5 \times (260/12) \times (18 \times 12)^4}{384 \times 30 \times 10^6 \times 130.1} = \frac{20.47}{130.1} = \underline{\underline{.157 \text{ in.}}}$$

The deflection without water would be:

$$\Delta = \frac{149}{260} \times .157 = \underline{\underline{0.090 \text{ in.}}}$$

These deflections are of the same order of magnitude as the irregularities in line and grade for sewer pipe. It is not expected that the beam deflections will have any effect on the test results and no shims will be used under the sewer pipe to correct for deflection under load.

In each 18-foot segment of sewer pipe one tee is included for inspection of the interior of the pipe and for sampling.

The effect of service connections to the sewer will be determined using the tees which are included in the test sewers.

Service connections are made to actual sewer lines through small diameter wyes or tees. These connections may enter the sewer at a variety of angles ranging from nearly vertical to nearly horizontal. Service connections may also be made by breaking into an existing section of sewer pipe and grouting a wye saddle in place. In the flushing evaluation equipment tees are provided every 18 feet. The tees are normally in the vertical position where they would only affect the flow near the flush tank at high flushing discharge rates. These tees will be extended with a length of pipe and turned to a nearly horizontal position during an early sequence of flushing tests to determine the effect of service connections on flushing effectiveness.

Short, 2-foot sections of pipe mitered four degrees on the end are used to make the curved portions of the test sewers. The curved portions of the pipe are supported at ten foot intervals and can be adjusted vertically in the same manner as the straight sections of pipe. The total length of each of the test sewers is approximately 800 feet.

The test sewers discharge through vertical flexible ducting to diverters. Different lengths of ducting can be installed to accommodate the change in elevation of the test pipes as the slopes are changed. The diverters can be pivoted to discharge either into a trough leading to the waste sewer or into a catch basin. The catch basin is provided with baffles, overflows, and drains to facilitate handling various quantities and rates of flow and taking samples.

Flush tanks are provided at three locations along the test sewer. The primary flush tank is located at the head end of the test sewers above the manhole bottoms. This tank has a volume of 100 cubic feet and is closed with a gasketed cover to permit experiments with vacuum or pressure operations. The tank discharges through either an 8-inch butterfly valve to the 12-inch test sewer or through a 12-inch butterfly valve to the 18-inch test sewer. The butterfly valves are actuated by air motors with the valve position controlled by the air pressure used. Thus the flushing water flow rate can be controlled by programming the air pressure to be applied to the valve actuator. The level in the flush tank and thus the flush water flow rate is measured by an air bubbler and a pressure transmitter and recorded on a high speed strip chart recorder. Air bubblers and pressure transmitters are also used to measure the variation in depth as selected points in the test sewers.

Intermediate flush tanks are provided at approximately 250 and 500 feet from the primary flush tank. The intermediate flush tanks have a capacity of 75 cubic feet and discharge through 6 and 8-inch butterfly valves. The intermediate flush tanks are installed at a great enough height to clear the test sewers when the test sewers are in their uppermost positions. Hoses are used to connect the outlet of the flush tank valves with the nozzles leading into the test sewer while providing for height adjustment.

Manhole bases are also provided at the intermediate flush tanks to simulate the approximate manhole spacing found in the laterals of many combined sewers.

In an actual sewer a junction between two or more sewers would normally be formed in the base of a manhole. In the flushing evaluation equipment junction channels will be provided in the base of the manholes at the intermediate flush stations in each sewer line. Gates will be used to close off the side channels when tests are to be conducted without junctions.

A view of the interior of the pipe during flushing will be provided by inserting view ports into the clay pipe downstream from each of the three flush tanks in each line.

Three 8 inch diameter windows will be used in the 12 inch pipe and four 8 inch diameter windows will be used in the 18 inch pipe to provide complete coverage from top to bottom of the pipe. The holes for the windows will be cut with a diamond hole saw to provide a smooth surface, free of cracks which could weaken the pipe. Acrylic sheet will be formed to match the inside surface of the pipe and will be sealed in place with silicone rubber caulking. Pressure forces will be taken by straps around the outside of the clay pipe.

A sewage recirculation pump is provided adjacent to the catch basin to pump sewage from the catch basin, through an overhead, 6" pipe and into the test sewer to simulate storm flow. The simulated storm flow will be used to check the amount of pollutional material remaining in the test sewer after a flushing test.

F. Cost Estimates for Phase II

The approximate costs for Phase II were estimated based on the equipment and program as previously described. Firmer definition of the task contents and more exact cost estimates will be presented in a subsequent proposal.

1.	Flushing Evaluation		
	a. Revise Design & Check	$ 17,000	
	b. Construct & Install Equipment	$134,000	
	c. Check out and Debug Test Equipment	$ 5,000	
	d. Conduct Flushing Evaluation Tests	$ 54,000	
	e. Formulate Design Procedure & Establish Application Criteria	$ 19,000	
	SUB-TOTAL	$229,000	$229,000
2.	Flush Station and Controls Development		$ 47,000
3.	Site Study and Selection for Demonstration		$ 8,000
4.	Preliminary Design & Estimating for Demonstration		$ 10,000
	TOTAL estimated cost for Phase II not including fee		$294,000

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SECTION III

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. Deposition of solids in combined sewers during the low flow of dry weather is one of the causes of the high pollutional load of combined sewer stormwater overflow.

2. The deposited solids can be removed from a length of combined sewer by an adequate volume of flush water.

3. The information available from the literature does not adequately define the engineering requirements and the efficiency of flushing equipment.

4. Tests must be made under controlled conditions in order to find out the cleaning efficiency under varying conditions of flush volume, sewer diameter, sewer slope, sewer length, etc.

5. Representative samples of sewage can be taken with available equipment if the samples are taken only from areas where the sewage is well mixed.

6. The flushing evaluation equipment which was designed will be adequate to perform the required testing.

B. Recommendations

It is recommended that this program be continued through Phase II including the following tasks:

1. Experimentally determine the requirements for effective flushing under various circumstances.

2. Integrate the above data into a design procedure preferrably in a computer program and determine the criteria for application of flushing systems to combined sewers.

3. Design and develop by test, the flush station equipment and control system.

4. Select a site for the Phase III demonstration and obtain the necessary approvals from local and state officials.

5. Make a preliminary design for the flushing equipment installation for demonstration. Estimate the costs of the demonstration and submit a proposal for Phase III.

SECTION IV

REFERENCES

A. Bibliography

1. Dobbins, Wm., "Quantity and Composition of Storm Sewage Overflows", A.S.C.E. Metropolitan Section, Symposium, April 17, 1962.

2. Riis-Carstensen, E., "System Design and Operation to Minimize Pollution," A.S.C.E., Metropolitan Section, Symposium, April 17, 1962.

3. Romer, H. "Problems Presented by Combined Sewers in Water Pollution Control," N.Y. Water Pollution Control Assoc., Schroon Lake, June 5, 1962.

4. Gameson, A.L.H. and Davidson, R.N., "Storm-Water Investigations at Northampton," Annual Conference of the Institute of Sewage Purification, Llandudno, England, June 22, 1962.

5. U.S. Dept. of Health, Education & Welfare, Public Health Service Division of Water Supply & Pollutional Control, Great Lakes-Illinois River Basins Project, "Report on the Illinois River System-Water Quality Conditions" Part I Text, Chicago, Illinois (1963).

6. Public Health Service Publication No. 1246, Pollutional Effects of Stormwater and Overflows from Combined Sewer Systems, A Preliminary Appraisal.

7. Temporary Flow Measurement in Sewers and Drains; M.H. Diskin, Proceedings of the ASCE, Vol. 89, No. HY4, July, 1963

8. Design and Construction of Sanitary and Storm Sewers; Water Pollution Control Federation, MOP-9, 1960

9. Fair, Geyer, and Okun, Water and Wastewater Engineering, 1966,

John Wiley & Sons, N. Y.

10. H.N. Ogden, Transactions of The American Society of Civil Engineers, 1898; 40,1.; Flushing in Pipe Sewers

11. Escritt, L.B. "Sewage Sampling" The Water and Waste Treatment Journal, 8, No. 10 (November-December 1961): Pub. Health Eng. Abs., 42:4 (1962) No. 629

12. Amberger, G., Rain Discharge and Sewage Sludge" Chemical Abstracts, 27, 18, 4608-9 (September 20, 1933); Pub. Health Eng. Abs.

13. Braine, C.D.C. "Design and Operation of Low-Head Self-Priming Siphons" Surveyor, 116, 1141-43 (November 2, 1957); (Pub. Health Abs.)

14. Anon. "Handling Sanitary Sewage and Storm Water" Round Table Discussion, Wastes Engineering, 31, 4, 215 (April 1960).

15. Raths, C.H. and McCauley, R.F. "Deposition in a Sanitary Sewer" Wat. and Sewage Wks., 1962, 109, 192; Water Poll. Abs. (Brit.) 36:6

16. Smith, A.A. "Optimum Design of Sewers" Civ. Engng. Publ. Wks Rev., 1965, 60, 206; Water Poll. Abs. (Brit), 38, (1965, No. 1468).

17. Ward, A.R. "Combined vs. Separate Systems of Sewerage" The Surveyor, 81, 2093, 299-300 (March 4, 1932); Eng. Index 1932.

18. Jarrett, P.N., Griffiths, H.F., and Markland, E. "Tests on a Model Stilling Pond with Siphon Overflow." Civ. Engng. Publ. Wks. Rev., 1964, 59; Water Poll. Abs. (Brit.), 39:10 (1964) No. 1623.

19. Stroia, E.J., and Voda, R.L. "Method of Cleaning Sewer Systems: (to Terra Chemical Corp.), U.S-P. 3, 170, 814; Chem. Abstr., 1965, 62, 10212; Water Poll. Abs. (Brit.), 38 (1965), No. 1808

20. "Sampling of Sewage," J Water Pollution Control Federation, 33, 6, 669 (June, 1961)

21. R.W. Purdy, "Industry's Idea Clinic," J Water Pollution Control Federation, 37, 4, 508 (April, 1965)

22. R.J. Burm and R.D. Vaughan, "Bacteriological Comparison Between Combined and Separate Sewer Discharges in Southeastern Michigan," J Water Pollution Control Federation, Part I, page 400, (March, 1966)

23. P.H. Woodruff, "An Industrial Waste Sampling Program," J Water Pollution Control Federation, 37, 9, 1233, 1965

B. Drawing List - Flushing Evaluation Equipment

1. Assembly Drawings

FMC Drawing Number	Title
E4317900	General Arrangement
E4323780	Flow Splitter Platform
D4323733	Flow Splitter Assembly
E4317853	Supply System
D4317871	Primary Flush Tank Piping
D4317899	Intermediate Flush Tanks
E4317851	Test Pipe Support Assembly
D4317903	Pipe and Beam Assembly - 12"
D4317902	Pipe and Beam Assembly - 18"
E4317882	Diverter Assembly
E4317898	Diverter Trough
D4317881	Catch Basin Tank
E4317901	Tank Assembly

2. Detail Drawings

FMC Drawing Number	FMC Drawing Number
E4317883	C4317897
E4317854	C4317876
D4317906	C4317878
D4317891	C4317874
D4317885	C4317877
D4317884	C4317875
D4323781	C4317896
D4323782	C4317895

C4317880

C4317890

C4323807

C4323806

C4323783

C4323784

C4323814

B4323790

B4323789

B4323785

B4323786

B4323787

B4323788

B4317892

B4317893

B4317872

B4317873

B4317886/7

B4317888/9

B4323804

B4323791

B4323812

A4323792

A4323793

A4323794

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